Scaling at western Nagano, Japan from spectrum analysis

Hisao Ito

Geological Survey of Japan/AIST

July 24, 2003

Earthquake Energy Workshop
Livermore

The same scaling law for large earthquakes and small earthquakes?

Breakdown?

(Kanamori and Heaton, 2000)

Although the determination of M_0 can be made accurately, the determination of E_R is still subject to large uncertainties. The values of E_R estimated for the same earthquake by different investigators often differ by more than a factor of 10 [*Singh and Ordaz*, 1994; *Mayeda and Walter*, 1996]. In particular, the values determined from

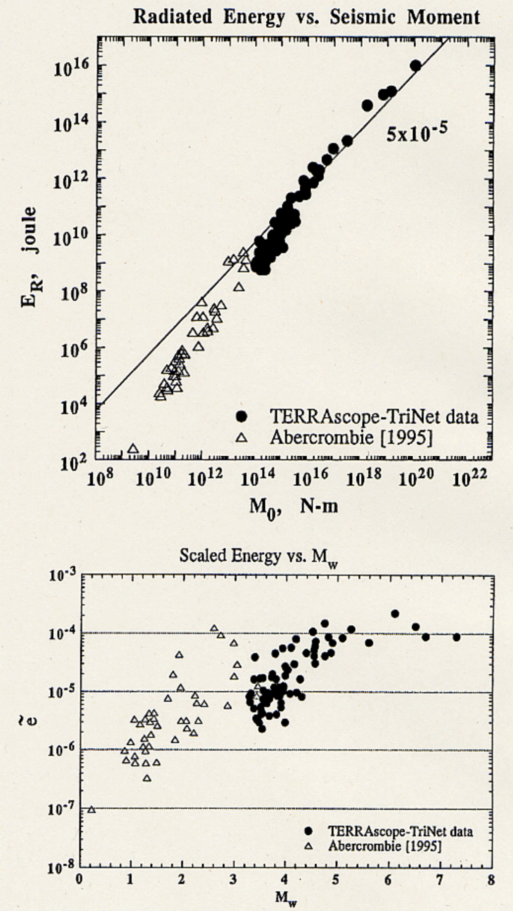


Figure 5. a). Relation between the radiated energy E_R and the seismic moment M_0. The data for large earthquakes (solid

Breakdowns are artifacts due to missing energy problem? (Ide and Beroza, 2001)

IDE AND BEROZA: DOES APPARENT STRESS VARY WITH EARTHQUAKE SIZE? 3351

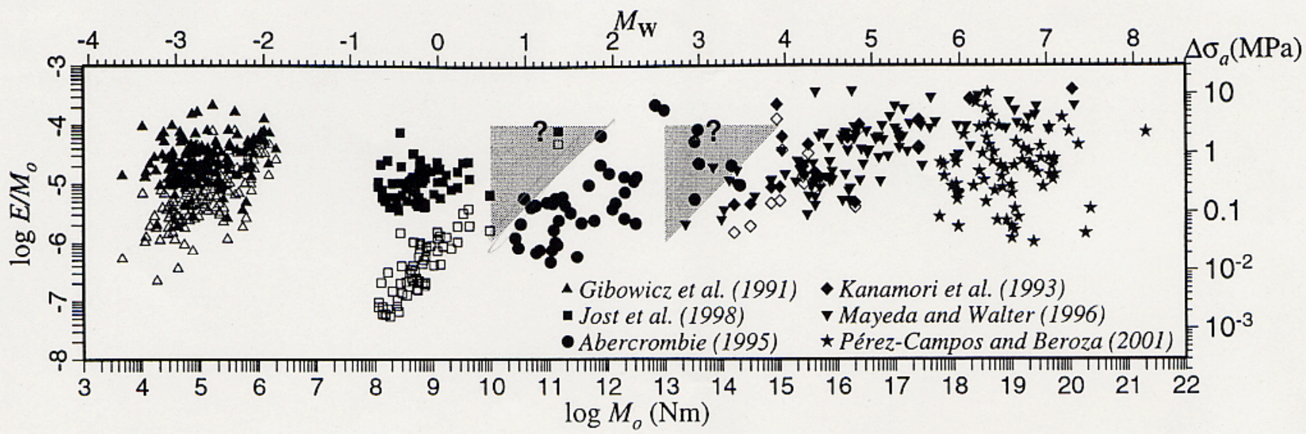


Figure 3. Energy-seismic moment ratio and apparent stress. Each symbol denotes a different data set as shown. Solid symbols are adjusted values or those that already accounted for the missing energy. Open symbols are the original values. Two gray triangles are the area where possibly missing events would locate.

Scaling relationship

- Problems:

Influence of source, path and site effects

Western Nagano

Seismic activity

earthquake swarms 1976, 1978

volcanic eruption of Mt. Ontake 1979

1984 Western Nagano earthquake (M 6.8)

shallow seismic activity

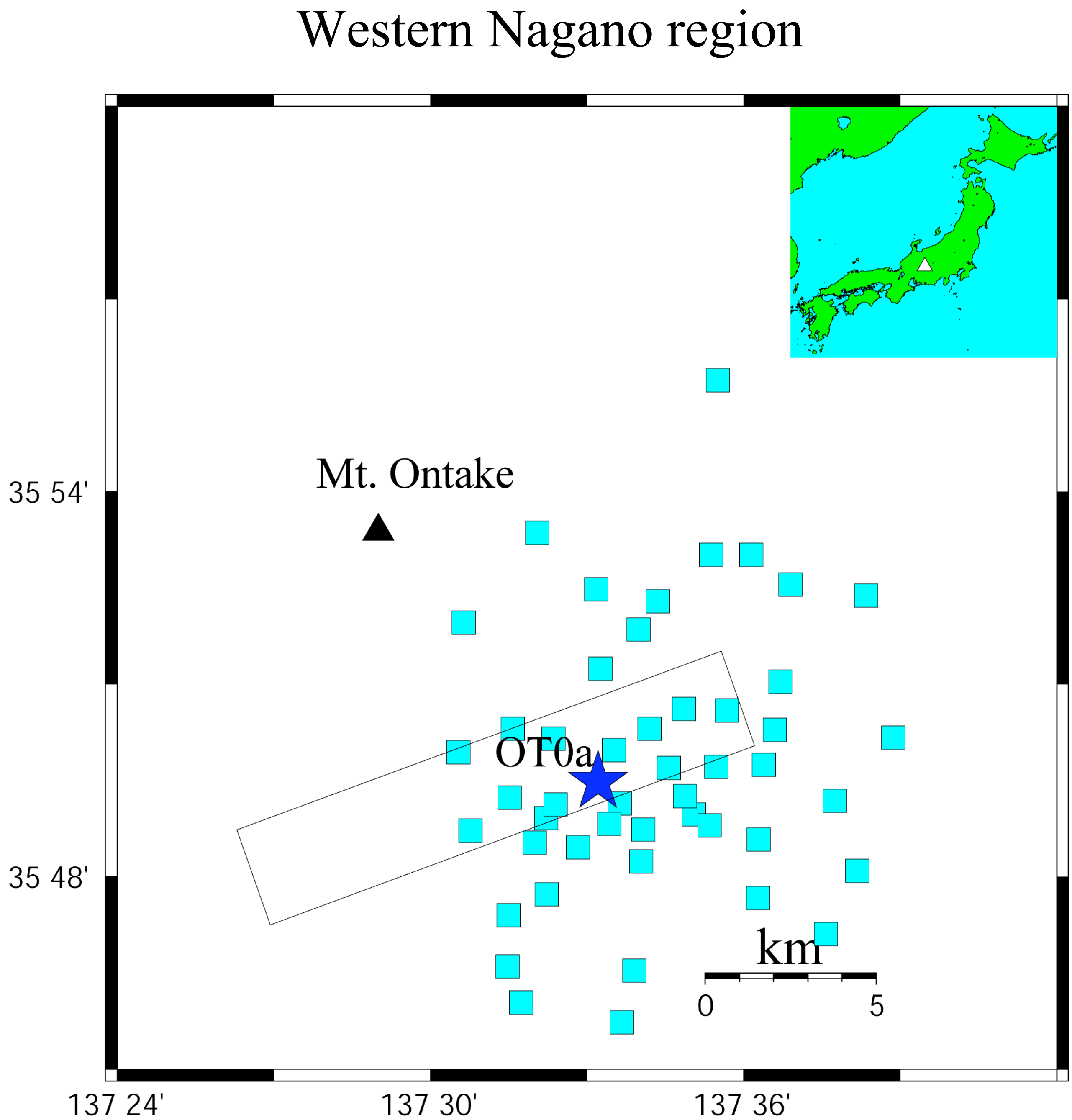
Dense surface seismic network (Iio et al.)

Borehole recordings

2Hz 3-comp. velocity sensor

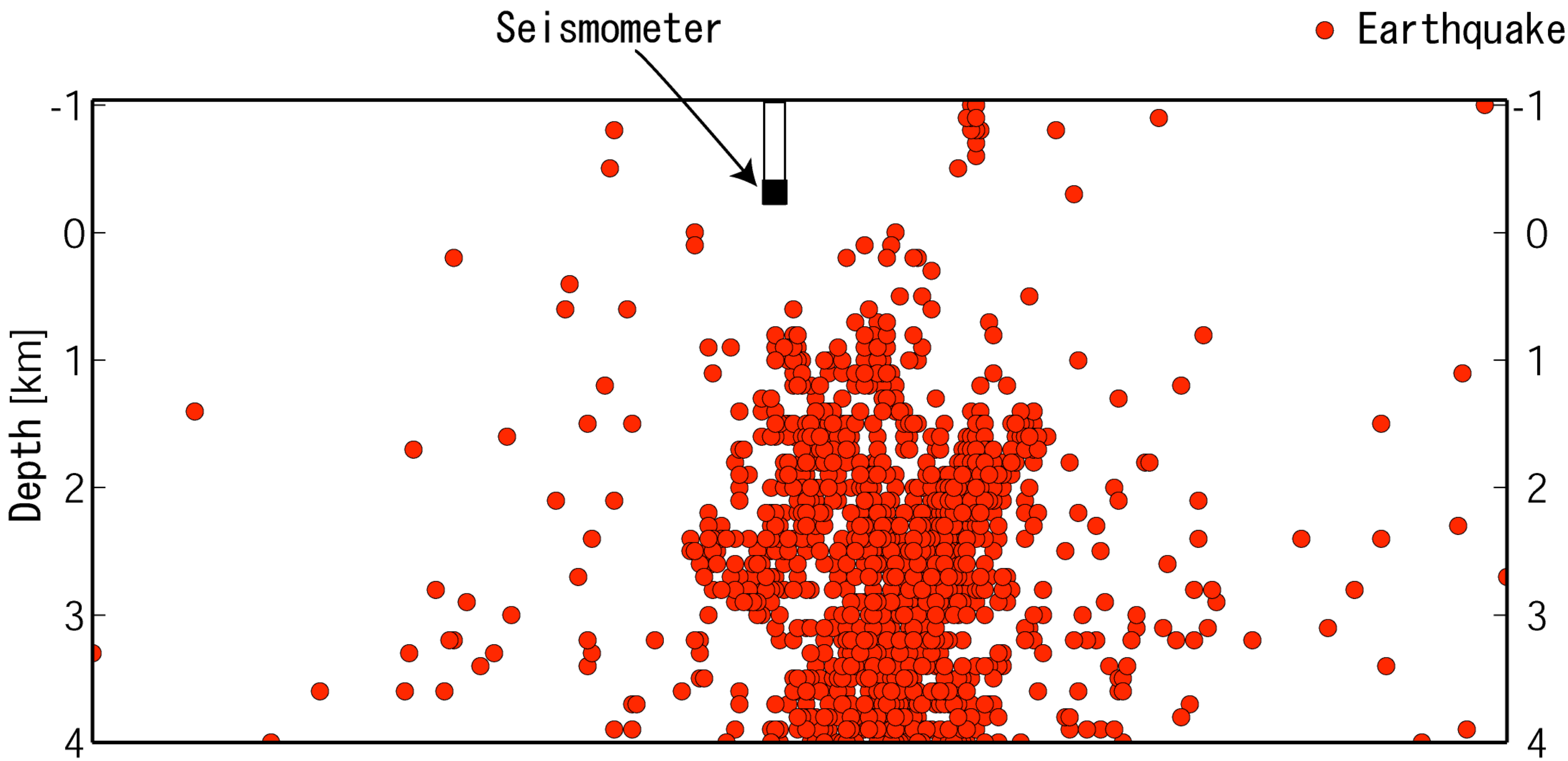
In close proximity of hypocenters

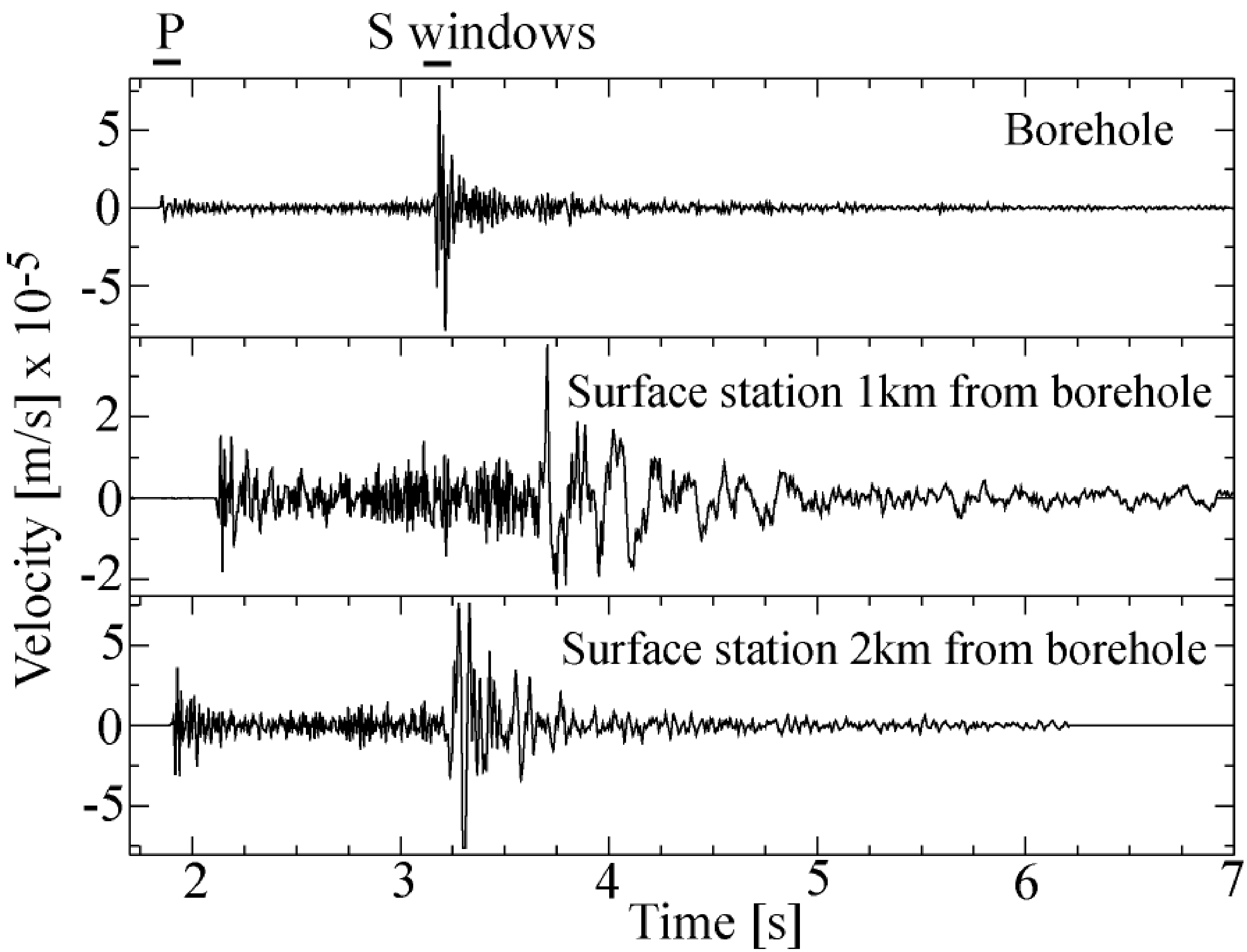
High frequency recording: 10 kHz


Western Nagano region
Mt. Ontake
OT0a
km
0
5
35 54'
35 48'
137 24'
137 30'
137 36'

Western Nagano

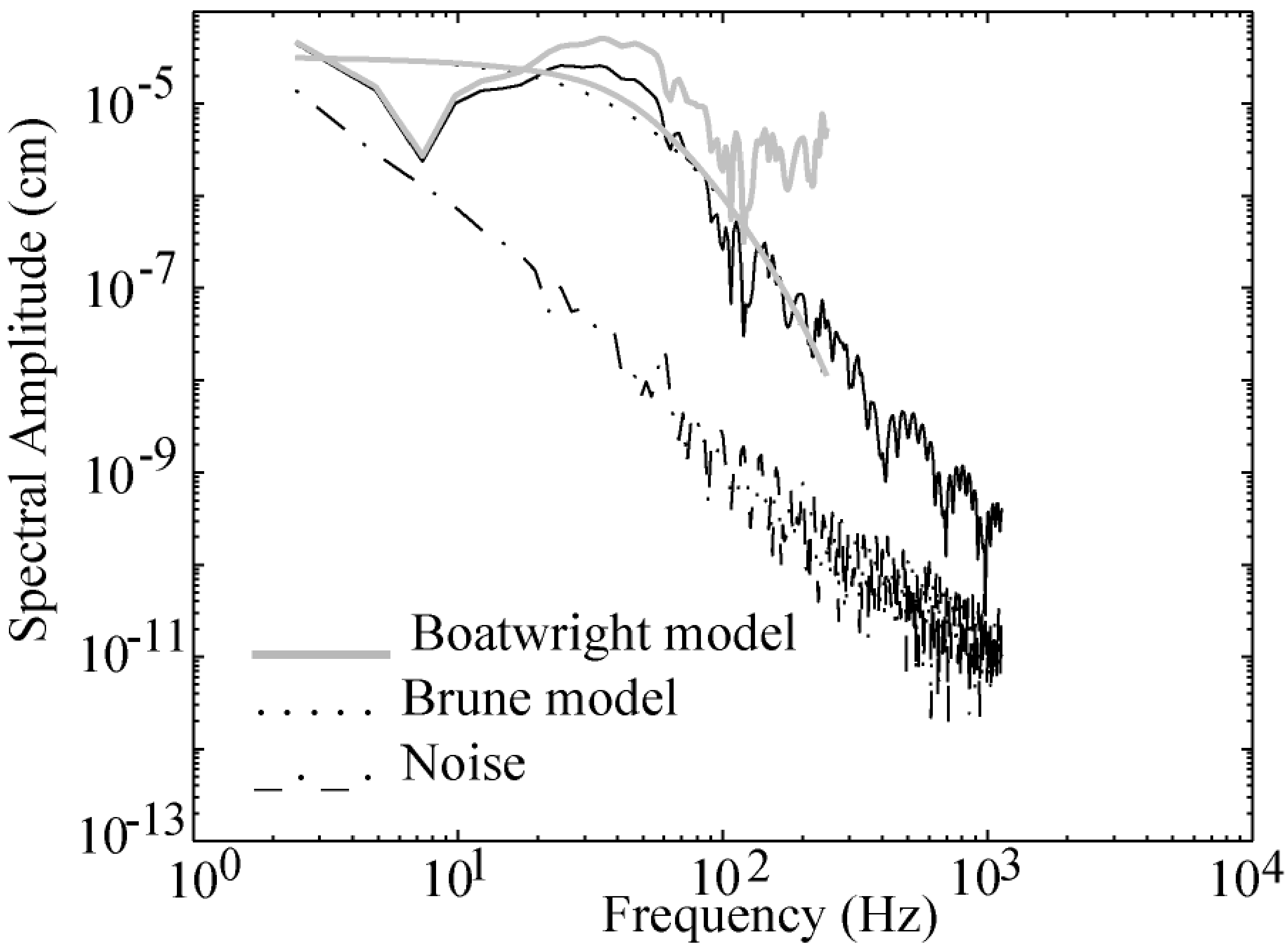
Shallow seismicity
GSJ Borehole with 3-component seismometer (2Hz velocity)





P
S windows
Borehole
Surface station 1km from borehole
Surface station 2km from borehole
Velocity [m/s] x 10-5
Time [s]
5
0
-5
2
0
-2
5
0
-5
2
3
4
5
6
7

Spectrum Analysis: An example of ω^2 model fitting



Constant Q model

Brune (1970) and Boatwright (1978) ω^2 source model to P and S wave amplitude spectra

(No significant difference in two models)

Average of $Q_P = 300$ and $Q_s = 560$

Spectrum analysis

ω^2 source model $$\Omega(f) = \frac{\Omega_0 \exp^{\frac{-\pi f t}{Q}}}{\left[1 + \left(f / f_c\right)^2\right]}$$ Brune (1970)

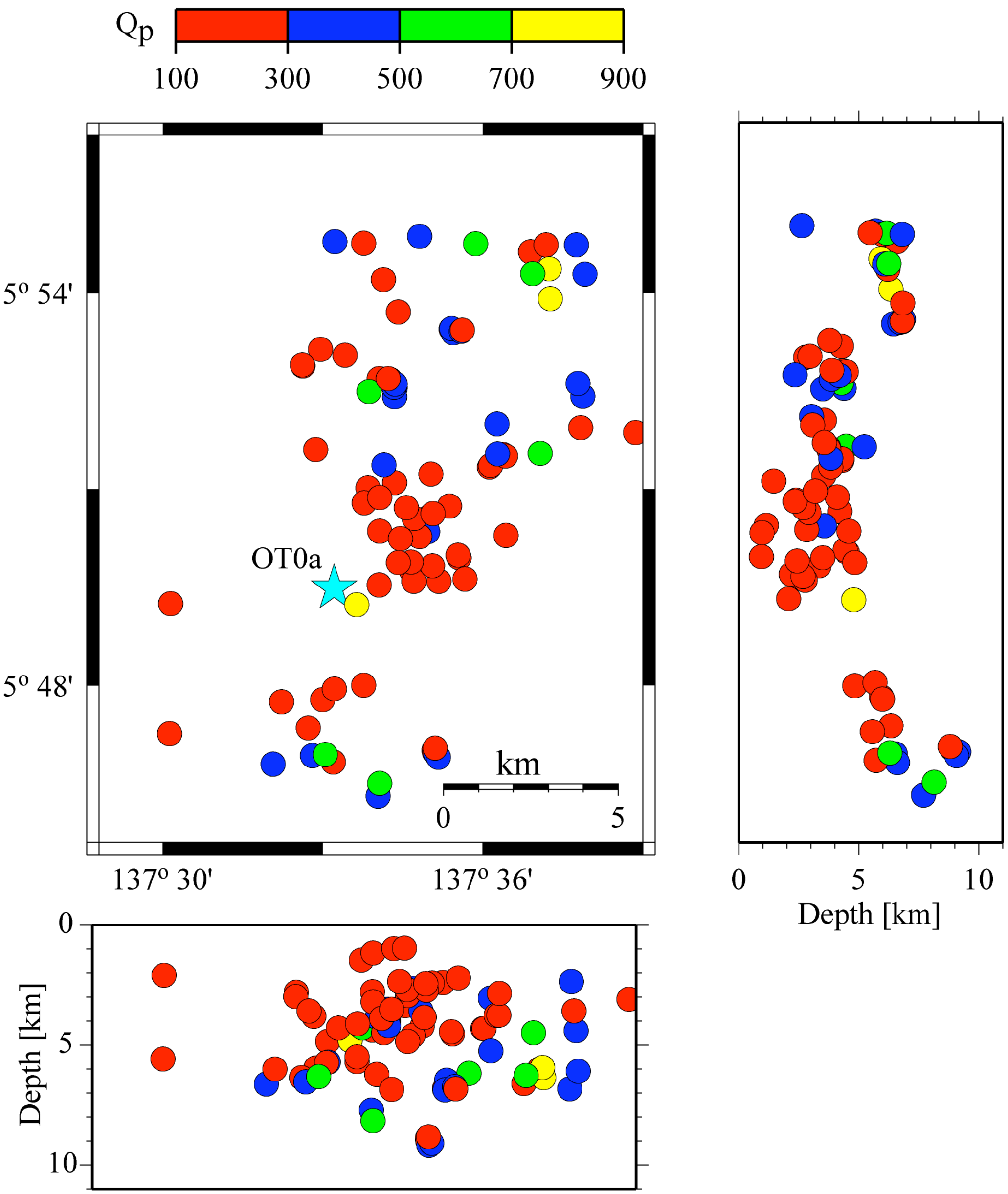
$$M_o = \frac{4\pi\rho v^3 d \Omega_o}{F}$$

$$r = \frac{Cv}{2\pi f_c}$$ Sato and Hirasawa (1973)

$$\Delta\sigma_s = \frac{7M_0}{16r^3}$$ Eshelby (1957)

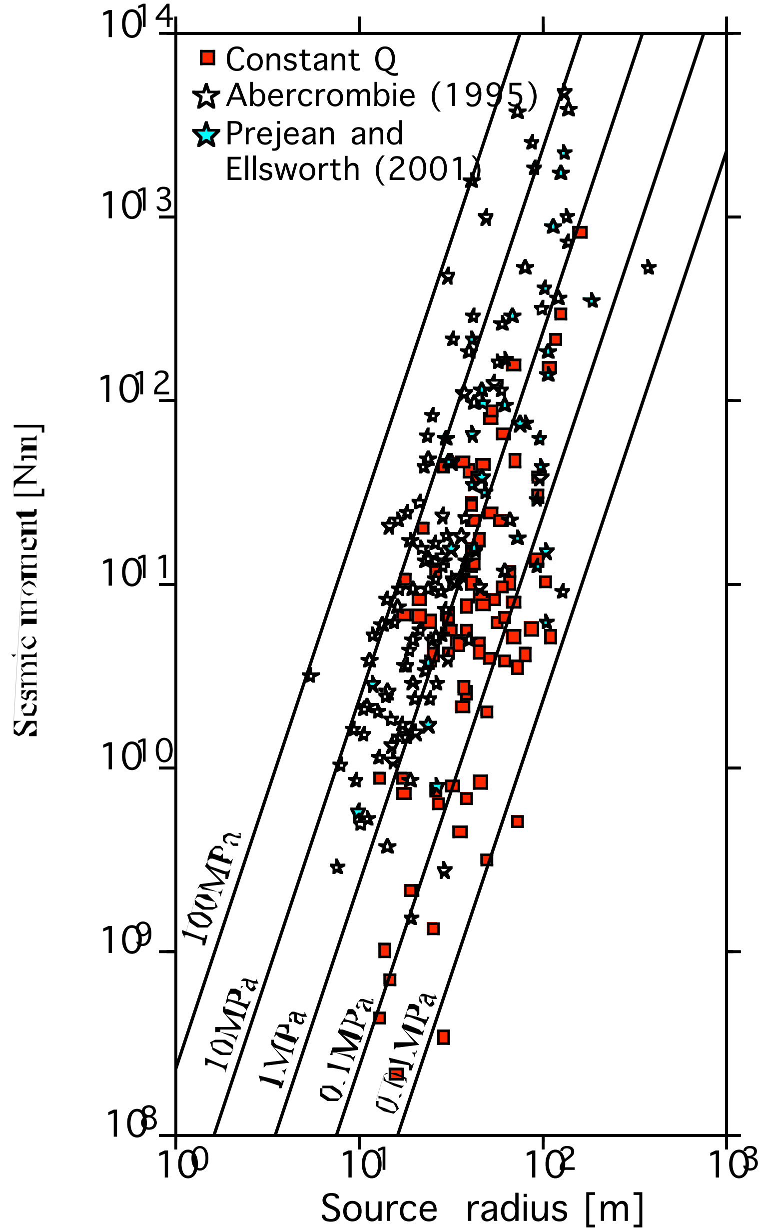
$$E_s = \frac{4\pi\rho v d^2 \langle F \rangle^2 \int \dot{u}^2 df}{F^2}$$ Boatwright and Fletcher (1984)

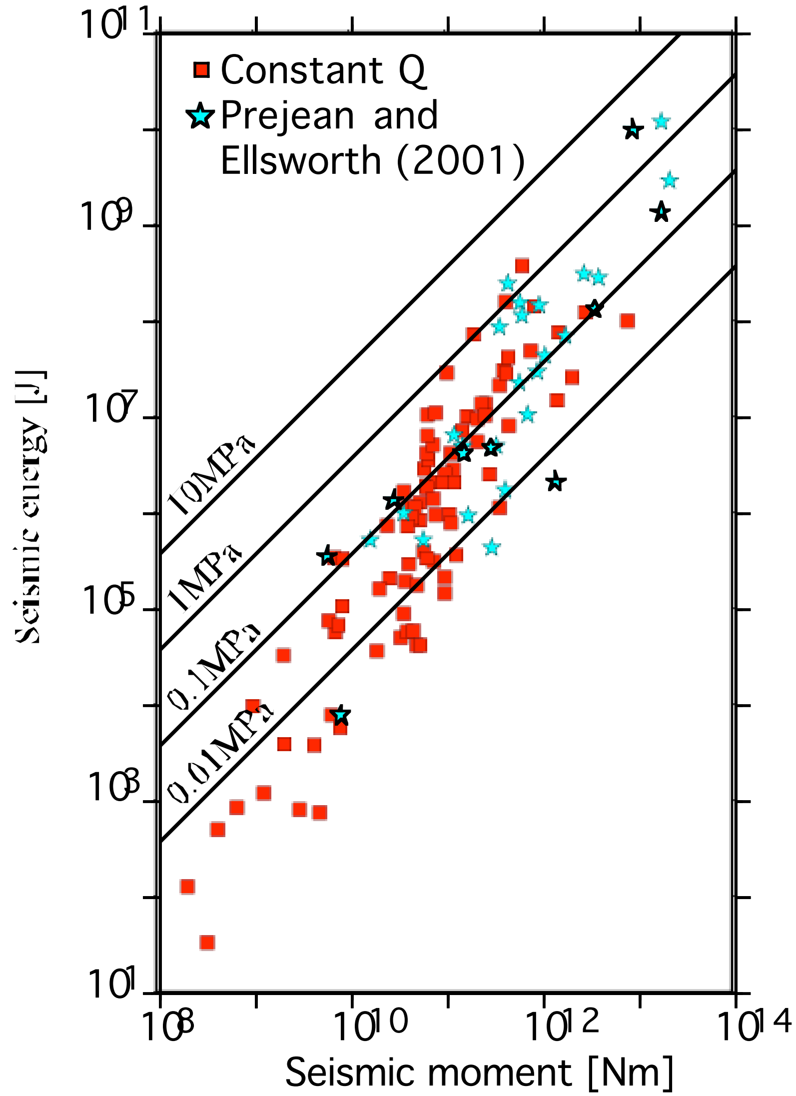
Q from constant Q analysis Qp=300, Qs=560



Seismic moment versus source dimension

slightly lower than previous studies (Abercrombie, 1995)





Constant Q
Prejean and Ellsworth (2001)
10MPa
1MPa
0.1MPa
0.01MPa
Seismic energy [J]
Seismic moment [Nm]

Estimation of frequency dependent Q

- Previous works

Yoshimoto et al., 1993: extended coda analysis method
Matsuzawa et al., 2003: twofold spectral ratio method

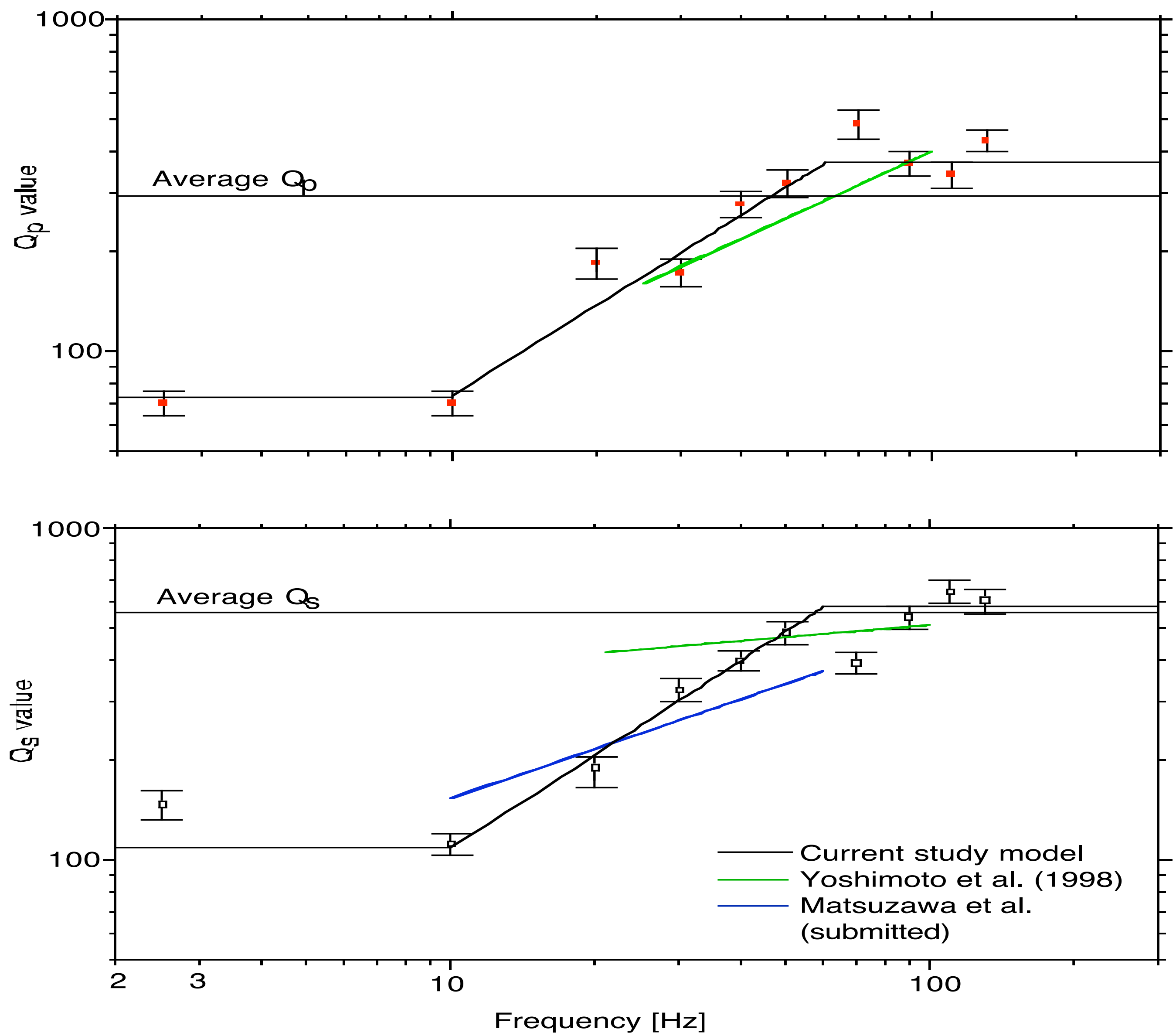
- Present works

Frequency range: 2.5Hz ~ 130 Hz
Similar results in 20Hz~40 Hz

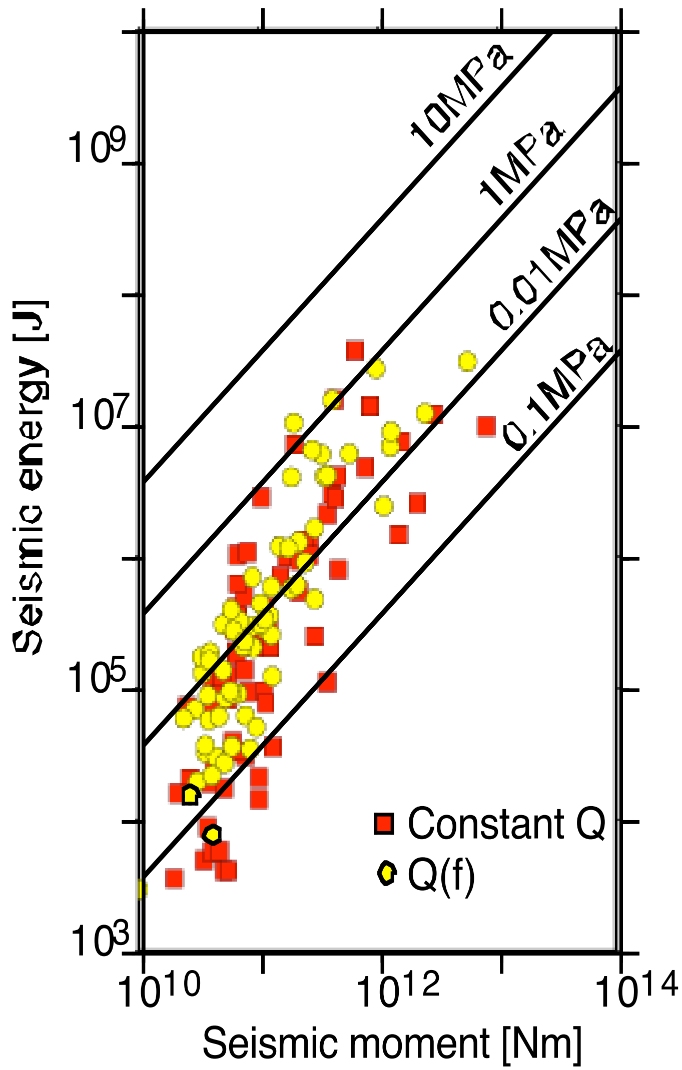
Low frequency: $f<10$
High frequency: $f>60$

-

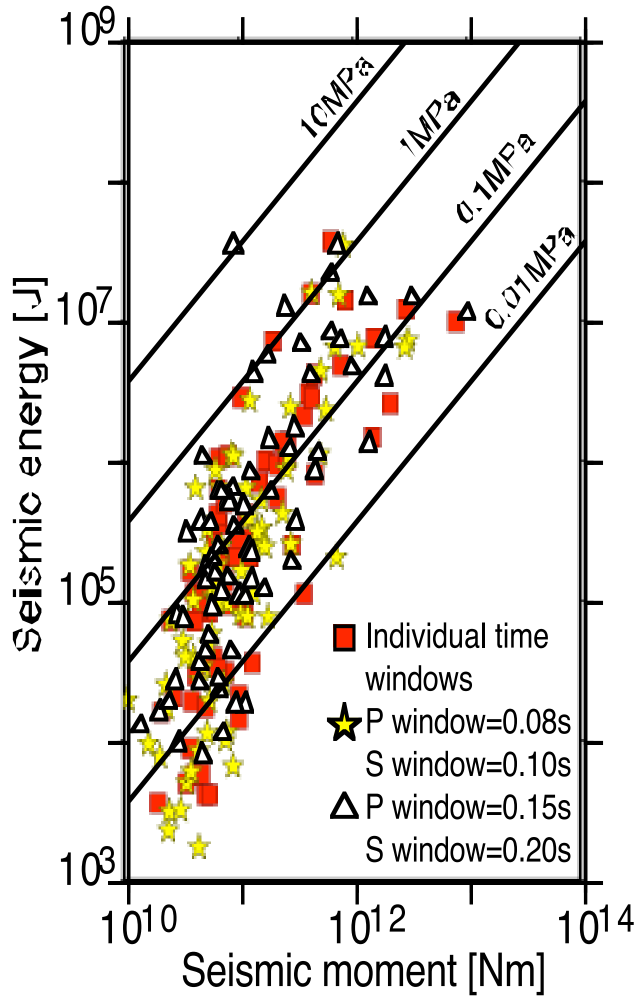
Variation of Q with frequency for P and S waves with standard deviations.
The average values are from constant Q analysis.



Seismic Energy corrected by frequency dependent Q



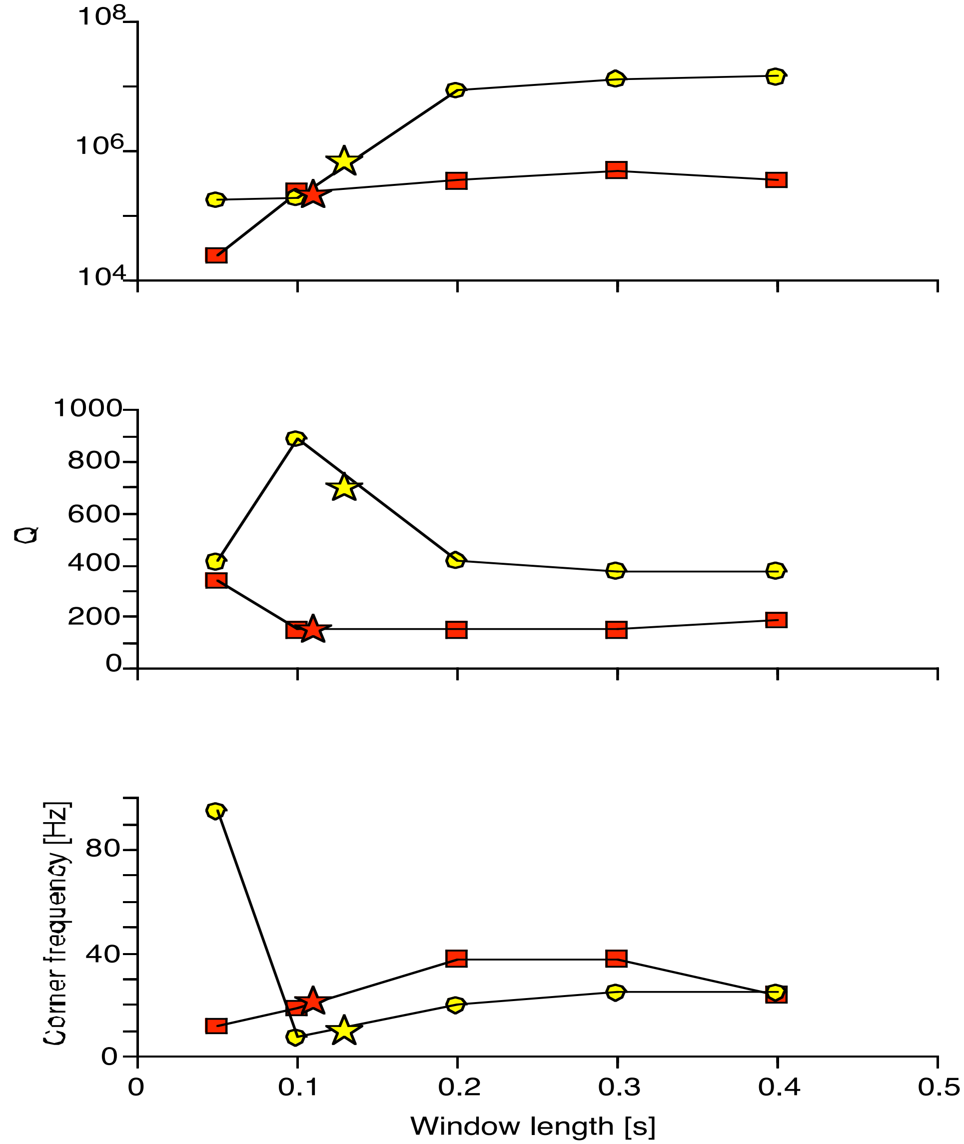
Differ from constant Q analysis for larger moments 10^{11}Nm.



Seismic energy [J]
10^9
10^7
10^5
10^3
10MPa
1MPa
0.1MPa
0.01MPa
Individual time windows
P window=0.08s
S window=0.10s
P window=0.15s
S window=0.20s
10^{10}
10^{12}
10^{14}
Seismic moment [Nm]

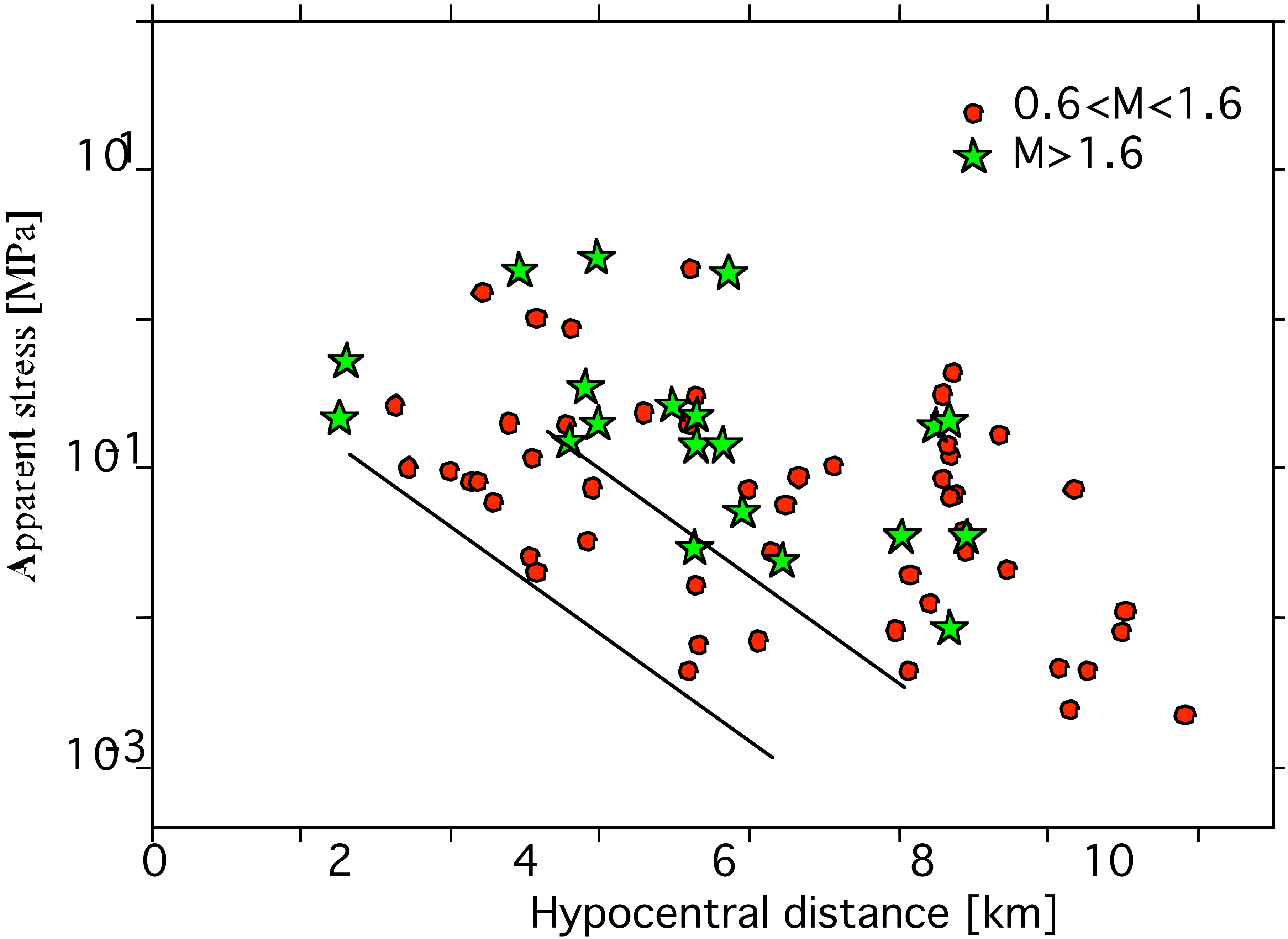
Effect of window length

- Variation of E_s, Q and f_c with time window length in constant Q analysis for P waves (squares) and S waves (circles). Stars indicate results for original individual event time window lengths.



Effect of Window Length

Seismic energy can vary by an order of magnitude depending on the window length used and corner frequency also varies over about 20Hz. Both these results indicate that stress drop and s_a are probably only accurate to an order of magnitude.

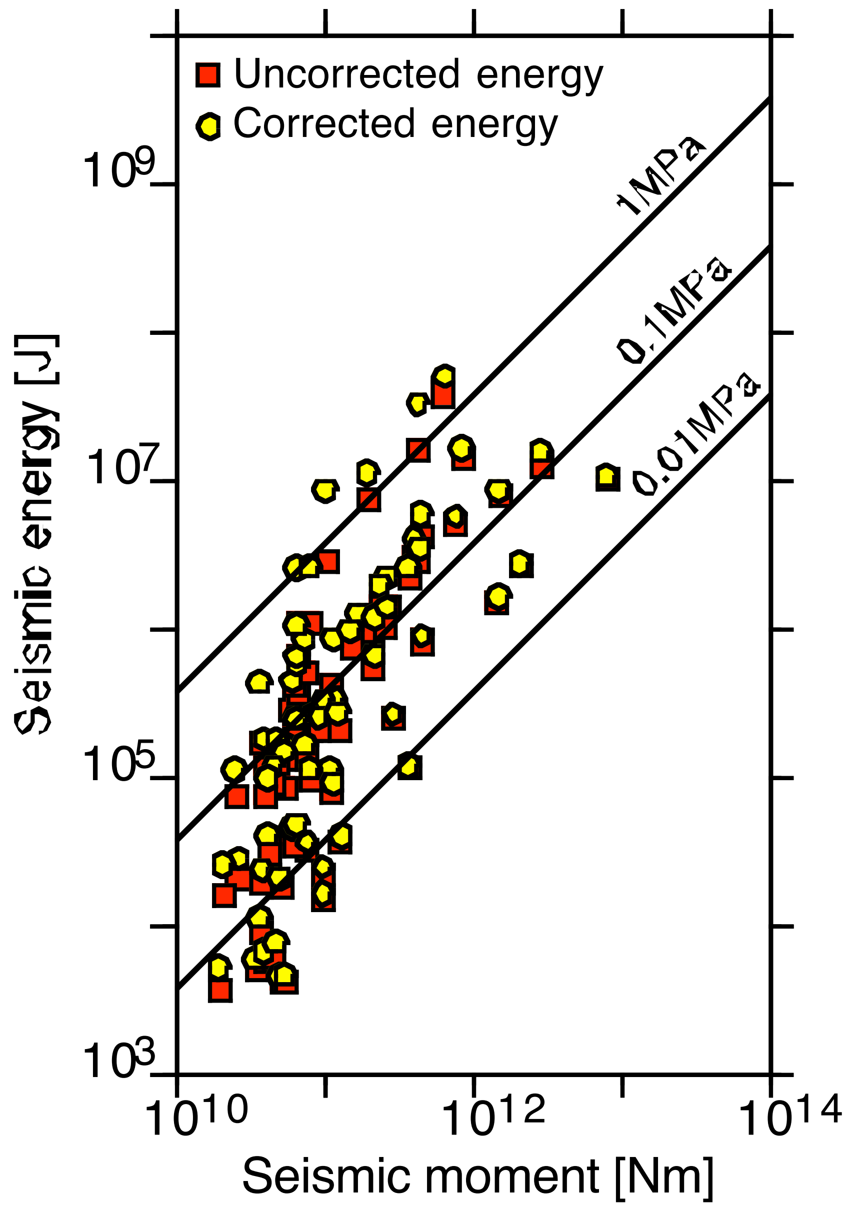


0.6<M<1.6
M>1.6
Apparent stress [MPa]
Hypocentral distance [km]
0
2
4
6
8
10

- Source complexity: does not play a role in the observed scaling relations.

- Limits in recording frequency: negligible

- Path effects: important



Uncorrected energy
Corrected energy
1MPa
0.1MPa
0.01MPa
10^9
10^7
10^5
10^3
10^{10}
10^{12}
10^{14}
Seismic energy [J]
Seismic moment [Nm]

Conclusions

- The 800 m borehole data provide a wide frequency bandwidth and greatly reduce ground noise and coda wave amplitude compared to surface recordings.
- Source parameters for 90 small earthquakes ($-0.5<M_w<3$) in western Nagano, Japan were investigated to determine the scaling of static stress drop and apparent stress with seismic moment.
- Source parameters were estimated with the best fitting ω^2 model function.
- No fall off in static stress values were observed but, for moments below 10^{11}Nm, a change in apparent stress scaling was observed.
- The results show a gradual decrease in stress with hypocentral distance indicating path effects are the most likely reason for the lower apparent stress values.
- No break down in $\Delta\sigma_s$ scaling with moment was found and a lower value (10^{11}Nm) than in previous studies (Abercrombie, 1995; Prejean and Ellsworth, 2001) was obtained for the change in apparent stress σ_a scaling.

Further studies

Technical problems

Recording limitations

Recording system

Sensor P: 300 Hz, S: 200Hz

Need more near-by observations

Directivity Effects?

multiple boreholes? Vertical array in a borehole?

Compare different methods with the same datasets